Chapter 1

TRANSPORT AND DISPERSION OF AIRBORNE POLLUTANTS ASSOCIATED WITH THE LAND BREEZE-SEA BREEZE SYSTEM

by

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ABSTRACT

Two atmospheric tracer experiments were conducted in July 1977. SF_6 was released for a 5-hour period during each of two nights from a coastal power plant stack located at the El Segundo Generating Station in the Los Angeles Basin. The purpose of this study was to investigate the transport and dispersion of plumes released into the land breeze portion of a land breeze/sea breeze circulation system. Even though a portion of the plume was apparently injected above the base of the nighttime inversion, essentially all of the tracer was observed to return across a control surface (from sea level to the base of the inversion) along the coast throughout the sea breeze regime during the following day. The residence time distribution functions of tracer material over the sea were almost identical in both experiments. The average residence time for tracer material over the ocean was 10 hours in both cases; however, some of the tracer spent as much as 16 hours out over the sea. The horizontal dispersion of tracer was also greater than expected, with between 75 and 100 km of coastline impacted by the return of SF_6 from a single elevated source. Data from both shipborne and coastal monitoring stations indicated that the path followed by the tracer over the ocean could not have been tracked accurately using trajectories constructed from conventionally available meteorological data.

1. Introduction

Coastal emission sources present special difficulties for air quality control programs because of the complexities associated with coastal meteorological processes. Differential heating of land and sea surfaces often generates an inland flow of air during the daylight hours. However at night, the land cools faster than the sea, and the wind may reverse direction. The fate of pollutants emitted into the nighttime offshore breeze is difficult to evaluate using conventional air quality models because of the lack of meteorological data needed to describe the flow reversal and mixing processes over the water.

The objective of the present study was to explore the transport and dispersion of elevated plumes released into the land breeze portion of a land breeze/sea breeze circulation system. An inert gaseous tracer, SF_6, was used to determine the extent to which pollutants sent seaward at night from elevated coastal Los Angeles emission sources by a land breeze could return to the Los Angeles region at ground level during the next day's sea breeze. Multiple passes of the same air mass over coastal emission sources could lead to pollutant accumulation in the air basin of interest. In order to gauge the potential magnitude of this accumulation problem, the fraction of the emissions into the land breeze that returned the next day was determined, along with the degree of dilution observed and the retention time available for chemical reaction of pollutants while they resided in the marine environment.

2. Previous Studies of Land-Sea Breeze Transport Phenomena

Land-sea breeze circulation systems-- their extent, duration, frequency and intensity have been studied for many years (see for example Eatontown Signal Laboratory Group, 1945; Defant, 1951; Kraus, 1972; Scorer, 1978). It has been shown that sea breeze/land breeze systems influence air pollutant transport over the Great Lakes and East Coast regions of the United States (Lyons and Olsson, 1973; Lyons, 1975; Raynor et al. 1975; Lyons and Keen, 1976; SethuRaman and Raynor, 1980). But perhaps the most widely studied coastal breeze system is that associated with the Los Angeles region. Beginning in the late 1940's it was realized that the sea breeze portion of this coastal meteorological phenomenon dominates air pollution transport across the Los Angeles Basin (Beer and Leopold, 1947; Kauper, 1960; Taylor, 1962; DeMarrais, Holzworth and Hosler, 1965). In succeeding years, air pollution aspects of the Los Angeles land-sea breeze system have been explored by trajectory calculations, tetroon flights, fluorescent particle releases and SF_6 tracer studies.

Early studies of air parcel transport in the Los Angeles Basin were based on trajectories constructed from surface wind data (Edinger, 1948; Neiburger and Edinger, 1954; Neiburger, Renzetti and Tice, 1956; Taylor, 1962). Emphasis was placed on inland sea breeze transport of photochemically-reacting pollutants. Forward and backward trajectories were calculated between major source areas and inland receptor points such as downtown Los Angeles. In the absence of routine meteorological measurements over the ocean, only a few studies paid attention to the fate of materials transported seaward by the land breeze. Kauper (1960) analyzed meteorological and air quality data from a day during which the measured oxidant concentration exceeded 0.5 ppm in the afternoon at the coast near El Segundo. His conclusion was that transport of oxidant precursors offshore by the land breeze and subsequent reaction and onshore transport of oxidant by the following sea breeze caused the high concentration of pollutants observed at the coast. Kauper and Niemann (1975, 1977) conducted two studies to characterize interbasin pollutant transport. Their analyses utilized extensive pibal, surface, aircraft, and ship data to calculate the path of specific "parcels" of air as they moved from the Los Angeles Basin over water to downwind receptors. They concluded that high ozone levels measured at Oxnard during June and July, 1975, and at San Diego during October, 1976, were the result of ozone transport aloft from the Los Angeles Basin.

In order to study transport into zones of sparse meteorological data, tracer techniques can be employed. Holzworth, Kauper and Smith (1963) released three tetroons from downtown Los Angeles on a summer day and tracked their movement visually along generally inland trajectories. Pack and Angell (1963) released 88 tetroons from nine Los Angeles area coastal sites into both land and sea breeze flows and tracked their motion using radar mounted on Catalina Island. Of special interest were 4 releases made from Long Beach during two successive nights. One of the tetroons moved parallel to the coastline before being transported inland at about 4 a.m.; a second one spent the nighttime hours over water before recrossing the coastline at dawn, while two of the four tetroons moved seaward and spent considerable time over water before recrossing the coastline the next day with the afternoon sea breeze. Angell et al. (1972) monitored the three-dimensional motion of tetroons over the Los Angeles Basin. Most of those releases were into the sea breeze although the balloons were tracked at all hours of the day and night. They concluded that during the day, trajectories computed from surface wind data provide a reasonably good estimate of the motion in the lowest few hundred meters of the atmosphere. However, at night the situation is much more complex due to the presence of substantial wind shear in the vertical direction. As a result, quantitative evaluation of pollutant transport and dispersion processes that occur at night over the ocean will have to proceed by means other than surface wind trajectory calculations.

Information on pollutant dispersion can be derived from tracer experiments that employ fluorescent particles or SF_6. Fluorescent particle studies attempted in the Los Angeles area have met with mixed results. The fraction of the fluorescent tracer material released which can be accounted for at monitoring sites is often quite low, as experienced by Kauper, Holmes and Street (1955). Neiburger (1955) designed an experiment in which fluorescent particles were released into the Los Angeles nighttime land breeze, but the fate of the particles released could not be determined. Vaughan and Stankunas (1974) released fluorescent particles during the morning of seven days between the summer of 1972 and the fall of 1973. They obtained no information concerning the fate of emissions transported seaward at night.

Sulfur hexafluoride gas (SF_6) is a much better tracer than fluorescent particles when attempting to characterize the transport and dispersion of gaseous pollutants. SF_6 is detectible at concentrations less than one part in 10^{12} parts air. Ground level dry deposition, which adversely affects recovery of fluorescent particles, is eliminated because SF_6 is an inert gas. Drivas and Shair (1974, 1975) and Lamb et al. (1977) have employed SF_6 to investigate transport and dispersion of gaseous pollutants during daytime sea breeze conditions in the Los Angeles area. The nighttime seaward transport and dispersion characteristics within land-sea breeze systems remain to be determined.

3. Experimental Design and Procedures

On two occasions during July 1977, SF_6 tracer was released late at night into the stack of Unit 4 at the Southern California Edison Company's El Segundo Generating Station. Pilot balloon observations made at Hermosa Beach prior to each release indicated that an offshore land breeze set up aloft above 300 meters around midnight on these occasions and propagated downward with time. Tracer releases were initiated after the offshore flow was confirmed to exist at and above about 200 m in elevation. During Test 1, SF_6 was released at a rate of 5.0 g s^{-1} from 0005 hours to 0500 hours PDT on July 22, 1977. Test 2 occurred at an SF_6 release rate of 13.6 g s^{-1} from 2303 hours PDT July 23, 1977 until 0400 hours PDT July 24, 1977.

Prior to each release, SF_6 sampling was initiated aboard the U.S. Navy Research Vessel Acania as it cruised in a zig-zag pattern across the Santa Monica Bay downwind of the tracer release point. Air samples of 10-second duration were taken at one to five minute intervals using 30 cm^3 plastic syringes. Portable electron capture gas chromatographs placed onboard the ship permitted rapid feedback of tracer concentration information during each test. A description of electron capture detection of SF_6 is provided elsewhere (Drivas, 1974; Lamb et al. 1977). Calibration results show that SF_6 concentrations down to 10^{-12} parts SF_6 per part air are readily detected. For comparison, if the total amount of tracer released during each test were uniformly distributed throughout an air volume of 40 km by 40 km by 300 m (i.e. the air volume over the entire Santa Monica Bay from the sea surface to above the effective stack height of the power plant), then the average tracer concentrations would have been about 29 and 78 ppt for Tests 1 and 2 respectively. Ability to detect the power plant plume if encountered at the sea surface thus was reasonably assured.

Tracer releases were halted when the land breeze subsided. In anticipation of a reversal in wind direction associated with the following sea breeze, SF_6 sampling then was initiated at a network of 29 fixed coastal monitoring sites located from Ventura to Corona del Mar (see Fig. 1). Hourly average samples were collected consecutively from 0500 to 1700 hours PDT at these coastal fixed sites during both tests. SF_6 concentrations also were monitored hourly from July 19 through July 29 at Santa Catalina Island.

Automobile sampling traverses were conducted periodically along coastal highways between 1000-1427 hours PDT July 22 and between 0235-1540 hours PDT July 24. Grab samples were collected at 0.8 to 3.2 km intervals along coastal U.S. Highway 1 between Redondo Beach and Malibu, and along Interstate Highway 405 between the San Fernando Valley and either the Long Beach harbor area or northern Orange County. The purpose of the coastal fixed samplers and highway traverses was to assess the time and place at which pollutants sent seaward at night were returned back across the coastline.

Meteorological data were collected both at sea and on land during each test in order to assist explanation of the tracer concentrations observed. The depth of the mixed layer above the sea surface over Santa Monica Bay was established by continuous acoustic sounder recordings made aboard the R.V. Acania. Vertical temperature profiles up to 1000 m altitude were obtained by radiosondes released from the ship at 0200 hours, 0600 hours and 0900 hours PDT on both July 22 and July 24. In addition, the Acania was equipped with two masts instrumented to measure wind speed, temperature, dew point/humidity, temperature fluctuations and wind speed fluctuations at elevations of 4.2 m, 7.0 m, 14.7 m and 20.5 m above the sea surface. Sea surface temperature was monitored from a boom extending 3.1 m in front of the ship's bow. Meteorological data taken aboard the Acania are presented by Schacher et al. (1978, 1980). The ship's instrumentation is described in detail by Houlihan et al. (1978).

Data on winds aloft were gathered from a limited number of pibal releases conducted at Hermosa Beach near the point of tracer injection. Pilot balloons were launched at 5 times from 2100 hours PDT on July 21 through 0400 hours PDT on July 22, and at 9 times from 2100 hours PDT on July 23 through 0540 hours PDT on July 24. Wind speed and direction were recorded at 100 m intervals above sea level. Low strata inhibited the use of pibals at altitudes greater than 400 to 600 m on several occasions. Hourly observations of surface wind speed and direction can be obtained in the Los Angeles area at more than 50 land-based meteorological stations operated by the National Weather Service, local air pollution control districts, the California Air Resources Board and the U.S. Navy.

4. Tracer Test Results

Test 1 July 22, 1977

Pibal observations taken at Hermosa Beach at 2100 hours PDT on July 21 showed an onshore flow at the surface with an offshore flow aloft above 500 m elevation. By 2200 hours on that day, the land breeze had propagated downward to about 300 m elevation. Shortly before midnight, the land breeze was observed at the ocean's surface aboard the Acania as it cruised less than 10 km seaward from El Segundo. Starting at 0005 hours PDT on July 22, the SF_6 tracer was released into the offshore flow from the El Segundo power plant stack.

Radiosonde measurements taken at the ship at 0200 hours PDT showed that a strong temperature inversion based at between 200 and 240 m elevation existed over the Acania at that time. The acoustic sounder indicated the depth of the mixed layer to be about 200 m at 0000 PDT July 22. From that time until 0630 PDT the depth of the mixed layer above the ship remained at or below about 220 m (with the exception of a single value of 250 m recorded at 0220 hours PDT). At 0630 PDT, the top of the mixed layer rose above 220 m, and remained between 220 m and 280 m until noon (again with the exception of one measurement at about 200 m depth).

The trajectory of the SF_6 plume over the Santa Monica Bay was estimated from available meteorological data. Streaklines corresponding to plume centerlines were constructed from sparse upper level pibal data. Using Briggs' (1971) plume rise formula, the effective stack height of the power plant was estimated to be approximately 250 m. Plume rise calculations by the method of Schatzmann (1979) yield similar results (McRae et al, 1981). Thus during the SF_6 release, it appears that the plume would have risen at least to the base of the temperature inversion and possibly into the stable air mass within the inversion. Because of the uncertainties associated with plume rise calculations, possible plume trajectories in the horizontal plane were computed using pibal observations from two heights, 108 m and 315 m. Pibal measurements taken on the hour were assumed to apply to the following full hour. Surface wind data were used to compute horizontal transport for comparative purposes.

SF_6 tracer concentrations measured aboard the Acania and estimated plume locations are compared in Figure 2. On three occasions prior to 0530 PDT, the ship passed beneath the computed location of the plume: at about 0100 hours, between 0300 and 0330 hours, and again between 0430 and 0500 hours PDT. The mixing depth on all three occasions was below 200 m and no significant concentrations of SF_6 were detected, except that as the ship passed beneath the plume at 0325 and at 0437 PDT, very small amounts of SF_6 were detected (14 ppt and 11 ppt, respectively). At 0220 hours when the mixing depth above the ship briefly exceeded 220 m, the ship was located far to the south of the likely location of the plume.

Between 0530 and 0545 PDT, the first significant peak in SF_6 concentration (80 ppt) was recorded at the ship. At this time the top of the mixed layer was rising toward the 200 m level. The ship was well south of the plume centerline computed from 100 m wind data. Trajectories computed from 300 m winds would place the plume in the vicinity of the ship at that time.

At 0615 PDT the ship moved northward to recross the path of the plume. Between 0620 and 0640 PDT the depth of the mixed layer increased to 240 m. Shortly thereafter high concentrations of SF_6 were measured at sea level as the ship passed beneath the computed location of the plume. From 0830 until 1130 PDT the ship saw no less than 18 ppt of SF_6 at the sea surface as it cruised across the central portion of the Santa Monica Bay.

Between 0700 and 0800 hours PDT, net onshore sea breeze flow was established along the coastline from Ventura to northern Orange County. SF_6 concentrations greater than 10 ppt were first observed in air recrossing the coast between 0900 and 1000 PDT. For the next 8 hours, SF_6 continued to cross the coastline from north of Pt. Mugu to as far south as Long Beach, a distance of roughly 100 km, as shown in Figure 3.

SF_6 Mass Balance Calculations

In order to determine the residence time distribution of the stack gases within the marine environment, a mass balance was constructed for the flux of SF_6 tracer returning landward during the day following each tracer release. A control surface, generally paralleling the coastline, was constructed from seven straight line segments attached end to end such that each segment traversed a zone of common topographic conditions, as listed in Table 1. Surface wind stations lying along each stretch of coastline were reviewed. A station or pair of stations was chosen to represent air mass motion along each section of the control surface, as listed in Table 1. Whenever possible, the average of the wind speed and direction measured at two wind stations located as far apart as possible along each stretch of coastline was employed to estimate average air velocity along that entire coastal segment. This was done in order to reduce the effect of errors in a single wind station's record that could affect the large air fluxes calculated across coastal flatlands.

Wind vectors apparent at each hour along each segment of the control surface were resolved into their components normal to the coast. The distance that the wind penetrated across each stretch of coastline during each hour was defined in this manner. Using the length of each control surface segment as a crosswind dimension, and the mixing depth data from the Acania as a vertical dimension, the volume of air crossing the coast within the surface mixed layer was determined at each hour.

The control surface parallel to the coast was subdivided into short intervals approximately centered on each SF_6 monitoring site. This subdivision was accomplished by bisecting the distance between each adjacent pair of SF_6 sampling stations and then drawing a line perpendicular to the control surface from the midpoint between each pair of monitoring sites. In that manner, the volume of air crossing the coast during each hour was apportioned between SF_6 monitoring sites.

The SF_6 concentration averaged over each hour at each sampling station was assumed to represent the average concentration of SF_6 in the air flow assigned to the coastline interval surrounding it. SF_6 concentrations shown in Figure 3 were then converted to SF_6 mass fluxes within the surface mixed layer of the atmosphere crossing each coastal interval at each hour. By summing these SF_6 fluxes, a mass balance for SF_6 released and recovered was constructed, and the residence time distribution of the tracer and associated emissions over the ocean was determined.

The results of the SF_6 mass balance from Test 1 are shown in Figure 4a. These calculations indicate that essentially all of the SF_6 released into the land breeze at night was observed to recross the coastline of the air basin within the surface mixed layer during the following day's sea breeze regime. Sixty-nine percent of the tracer material recrossed the Los Angeles County coastline along the Santa Monica Bay (near the release point), while thirty-one percent of the SF_6 returned across the Ventura County coastline near Oxnard to the north. Transport of such a large fraction of the tracer material northward into Ventura County would not have been predicted from trajectories drawn from available surface wind data.

Test 2 July 24, 1977

At 2200 hours PDT July 23, pilot balloons released from Hermosa Beach showed an onshore flow at 108 m elevation with offshore flow aloft at and above 216 m elevation. One half hour later, pibal observations indicated that the land breeze existed at 108 m elevation and above. At 2303 hours PDT the second release of tracer was begun from the power plant stack.

The first acoustic sounder measurements made following the start of this experiment place the base of the sub-tropical inversion at about 500 m above the Acania. A strong temperature inversion at that elevation persisted throughout the night as shown by both the acoustic sounder and the radiosondes taken at 0200 plus 0600 PDT. Between 1000 and 1100 hours PDT, the inversion base dropped from around 500 m to about 300 m elevation, then returned to 500 m briefly before stabilizing at a height between 260-350 m during the rest of the experiment.

Possible plume trajectories in the horizontal plane were computed using pibal observations at 108 m and 315 m elevations plus surface wind data. In Figure 5, SF_6 concentration measurements obtained aboard the Acania are co-ordinated with the ship's position and possible plume centerline locations. SF_6 was first observed at the sea surface aboard the Acania at 0144 hours, reaching a short term peak of 59 ppt at 0152 hours while the ship was very close to the coast at Santa Monica. Low levels of tracer were measured at the ship almost continuously thereafter. SF_6 was first observed at the surface at the coast from Santa Monica to Carbon Canyon Road (near Malibu) between 0250 and 0330 PDT during two automobile traverses along Highway 1. Concentrations up to 64 ppt SF_6 were found ashore at a point closely corresponding to the end point of the plume trajectory computed from 100 m winds shown in Figure 5.

At 0400 hours, the plume trajectories computed from Hermosa Beach pibal data and surface winds would suggest that the plume was confined to an area over Santa Monica Bay within 15 km of the coastline to the north and west of the release point. SF_6 measurements obtained aboard the Acania, however, show a quite different picture. The Acania first encountered high SF_6 concentrations (up to 461 ppt) shortly after 0400 hours PDT at a location well west of the plume trajectory computed from 300 m winds. After apparently crossing through the plume at about 0415 PDT, SF_6 concentrations dropped to a low of 34 ppt. The ship then executed a series of turns and eventually headed in a southeast direction parallel to the El Segundo coastline at a distance of about 20 km offshore. SF_6 concentrations at the ship were observed to increase continuously from 0600 hours to 0800 hours to levels above 250 ppt, although the ship was west or south of the computed position of the plume at most times. Southward motion of a portion of the plume over the ocean also is confirmed by the SF_6 monitoring station at Santa Catalina Island which recorded SF_6 concentrations up to 36 ppt briefly during the period 1200-1500 hours PDT.

Onshore flow was already apparent at the coast from Malibu southward when sampling commenced at 0500 hours at the coastal fixed monitoring stations. As in Test 1, the tracer material was observed to be transported over long distances within the marine environment before recrossing the coast the next day. In this case, the predominant direction of flow was more northerly (toward the south) than encountered during Test 1. Tracer material was measured recrossing both the Santa Monica Bay and Long Beach portions of the Los Angeles County coast, as well as along the Los Alamitos to Newport Beach stretch of the coast of Orange County to the south of Los Angeles (see Figure 6).

A mass balance for SF_6 released versus that returned inland by the sea breeze was constructed by methods previously described. The acoustic sounder showed a weak intermittent return during Test 2 at an elevation below the location of the sub-tropical inversion base. Mass balance calculations using that return height as a mixing depth would indicate a 49% recovery of the tracer released. Careful reexamination of the acoustic sounder records indicates that the sub-tropical inversion base was the true limit to vertical dispersion in this case. Using the base of the sub-tropical inversion as as estimate of the mixing depth during Test 2, 244 kg of SF_6 (essentially all of the SF_6 released) would have recrossed the coastal monitoring network (as shown in Figure 4b).

It is clear that selection of wind stations and mixing depths influences mass balance results. A sensitivity analysis of mass balance results was conducted independently by Sackinger et al. (1981). Their calculations also indicate that the great majority of the tracer material sent seaward at night during both Tests 1 and 2 returned inland the next day with the sea breeze.

5. Summary and Discussion

Results from both Tests 1 and 2 show that a major portion of the tracer material released into a land breeze at night from an elevated coastal emission source was advected back over the coast during the following day's sea breeze. Multiple passes of the same air mass over coastal point sources thus leads to pollutant accumulation within the Los Angeles basin.

The retention time for pollutants within the marine environment during these tests can be estimated from Figures 4a and 4b, and is shown in Figure 7. When normalized on the basis cf the total amount of SF_6 returned to land, the residence time distributions for SF_6 over the ocean during Tests 1 and 2 are remarkably similar. The median age of the material returned to land was about 10 hours in both tests. On a first in/last out basis, some of the emissions could have been retained over the ocean for up to 16 hours. Even relatively slow chemical reactions involving pollutants trapped in such a land/sea breeze circulation system would have considerable time to proceed toward completion before emissions returned to encounter receptor populations.

Dispersion of tracer material during these tests was much greater than expected. The tracer dosage accumulated along the coastal monitoring sites is given in Figure 8, and shows that SF_6 released into the land breeze from a single source crossed between 75 and 125 km of coastline during the following day's sea breeze. During both tests, at least some tracer material was found in the vicinity of trajectories drawn from surface or upper level wind data. But in both cases, the northward or southward edge of the returning tracer cloud was much farther from the release point than would be indicated by trajectories drawn from pibal releases made near the source. During Test 1, two pronounced peaks in SF_6 mass were observed to be crossing the coast simultaneously (see Figure 3), one near the SF_6 release point and another far to the northwest near the Ventura/Los Angeles County line. This plume apparently was dispersed by wind shear over the Santa Monica Bay.

In the case of Test 1, a description of transport and dispersion processes can be provided which is compatible with shipboard observations of SF_6 concentrations, mixing heights, inversion height, and data on winds aloft. The essential features are:

(a) The heated plume from the stack rises to the base of the inversion where it arrives still a little warmer than the ambient air but not as warm as the air a short distance above. The plume levels out at this height and partially penetrates the base of the inversion. The coolest plume material is below the inversion base and the warmest just above. Stronger winds aloft carry the upper parts of the plume farther out to sea than the lower portion which moves more nearly with the surface wind field.

(b) A mixed layer begins forming at the sea surface as air, previously cooled by contact with the nocturnally cooled land surface, crosses the coastline on the land-breeze and encounters the warmer ocean surface. The convectively mixed layer which develops grows in thickness as the heating from below continues, and in time the top of this mixed layer approaches the base of the inversion.

(c) Upon reaching the lower edge of the plume, the convective mixing motions fumigate SF_6 down to the sea surface. This fumigation process accounts for the observation that the SF_6 suddenly appeared at the sea surface after 0500 PDT but was not observed during three prior ship passages beneath the plume earlier in the experiment. Fumigation continues as long as plume material remains near the base of the inversion, in time distributing it almost uniformly from sea surface to inversion base. A detailed quantitative treatment of the convective downmixing processes which act on the plume during this experiment is provided by McRae et al. (1981), and shows that the time scales for convective mixing during this experiment are consistent with the above fumigation hypothesis.

(d) The plume material begins moving back toward land when the seaward limit of the land breeze begins to move toward land as the morning sea breeze develops. This zone of convergence between the land- and sea-breeze produces a swelling of the sub-inversion layer and can propagate through the atmosphere at speeds exceeding the sea breeze. The ship passed through this zone at 0735 PDT at which time the maximum mixing height, 280 m, was observed at the ship.

Results obtained during Test 2 would not have been explained by an air quality model using commonly available meteorological measurements. In particular, transport of material southward to Santa Catalina Island, Newport Beach and Corona Del Mar would not have been predicted from pibals launched near the SF_6 release point or from trajectories drawn from surface wind data. Uncertainties in the mixing depth estimates would have further complicated pollutant concentration calculations. Under these circumstances, a tracer like SF_6 is essential to an assessment of pollutant transport and dispersion.

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TABLE 1

Description of the Coastline Segments that form the Control Surface for SF_6 Mass Balance Calculations

	COASTLINE SEGMENT	TOPOGRAPHIC FEATURES	WIND STATION(S) USED TO CALCULATE AIR FLOW ACROSS COAST	SF_6 MONITORING SITES ALONG THAT SEGMENT OF COASTLINE
1.	Ventura to Pt. Mugu	Coastal Plain	Average of Ventura and Pt. Mugu	Stations 1 through 5
2.	Pt. Mugu to Pt. Dume	Coastal Mountains	Zuma Beach	Stations 6 and 7
3.	Pt. Dume to Pacific Palasades	Coastal Mountains	Malibu	Stations 8 through 10
4.	Pacific Palasades to Redondo Beach	Coastal Plain	Average of Venice and Redondo Beach	Stations 11 through 16
5.	Redondo Beach to Long Beach	Coastal Mountains	Average of Redondo Beach and Long Beach (APCD Station)	Stations 17 through 19
6.	Long Beach to Los Alamitos	Coastal Plain	Average of Long Beach (APCD Station) and Long Beach Airport	Stations 20 through 22
7.	Los Alamitos to Newport Beach	Coastal Plain	Average of Los Alamitos and Newport Beach	Stations 24 through 29

Figure Captions

Figure 1	Southern California showing the monitoring sites used during the tracer experiment.
Figure 2	SF_6 concentrations observed aboard the Acania, coordinated with the ship's position and possible plume centerline locations: Test 1.
Figure 3	Hourly average SF_6 concentrations measured at the coastline during Test 1.
Figure 4a	Material balance on SF_6 release and return: Test 1.
Figure 4b	Material balance on SF_6 release and return during Test 2, computed using mixing depths implied by the location of the sub-tropical inversion base.
Figure 5	SF_6 concentrations observed aboard the Acania, coordinated with the ship's position and possible plume centerline locations: Test 2.
Figure 6	Hourly average SF_6 concentrations measured at the coastline during Test 2.
Figure 7	Retention time distribution for tracer material within the marine environment. Symbols indicate time measured from the midpoint of the tracer release. Error bounds indicate the 5 hour span during which the returning tracer might have been released.
Figure 8	SF_6 dosage (ppt-hr) observed along the coastline per g-mole of SF_6 released during Tests 1 and 2.

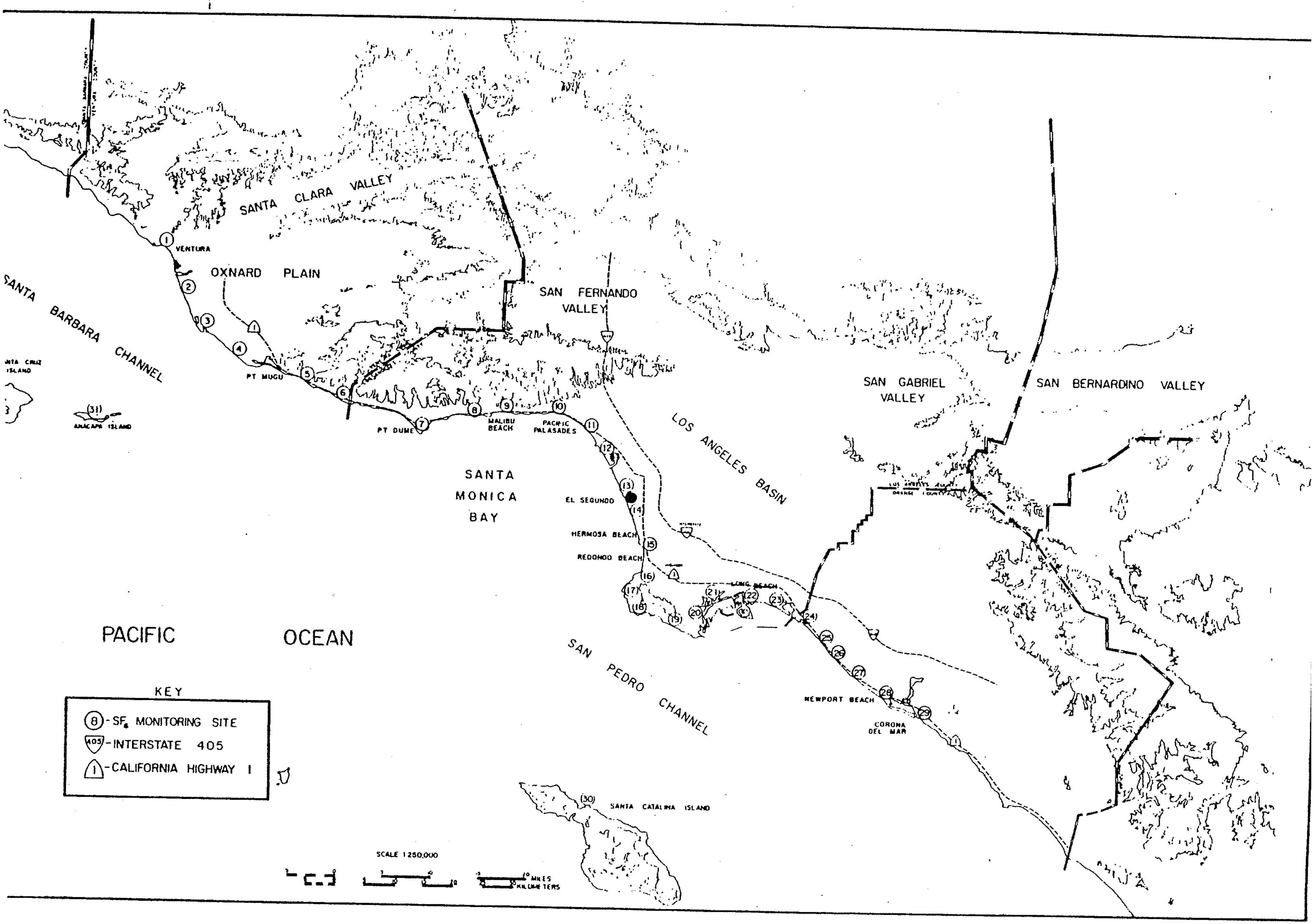
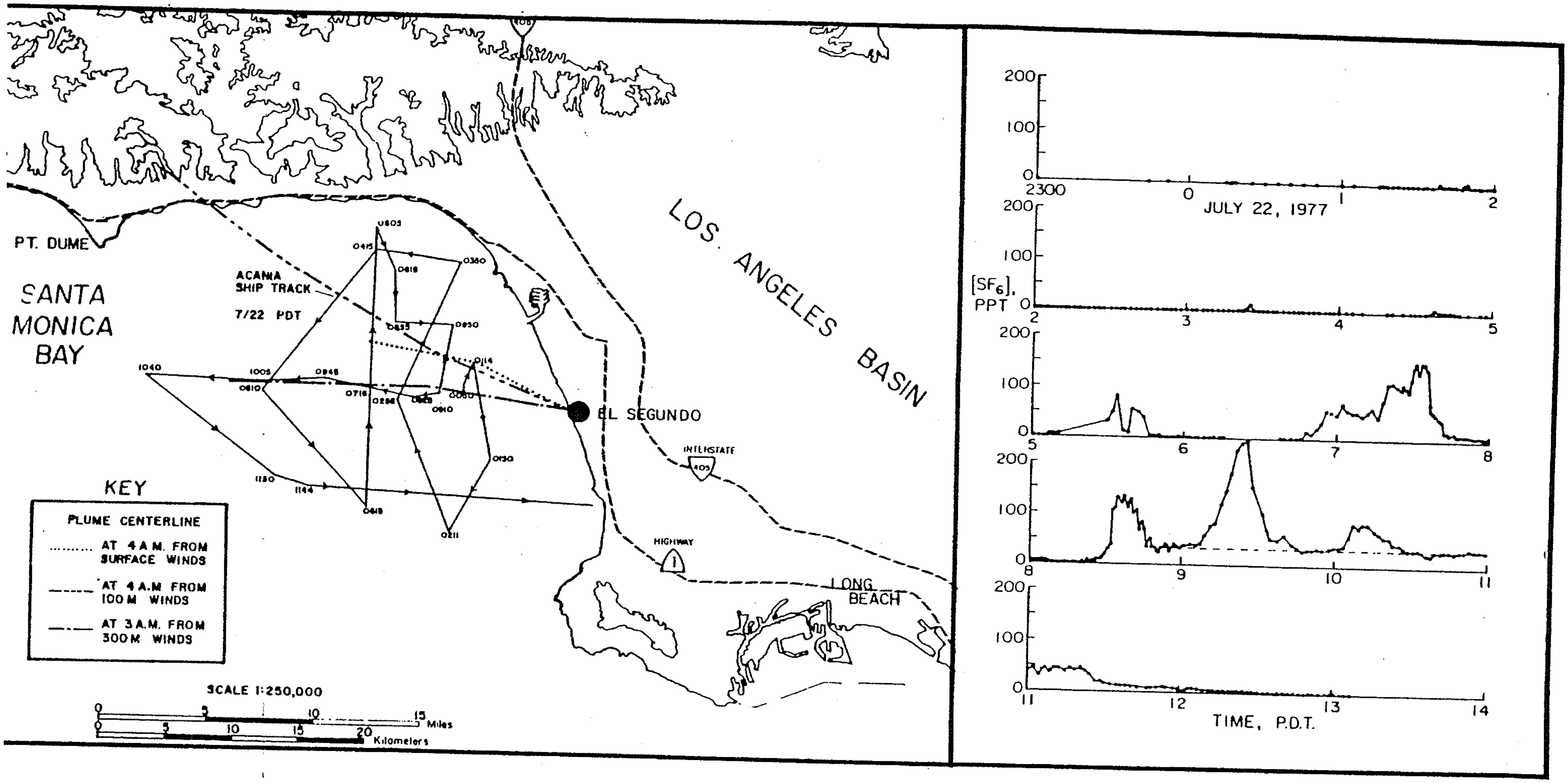
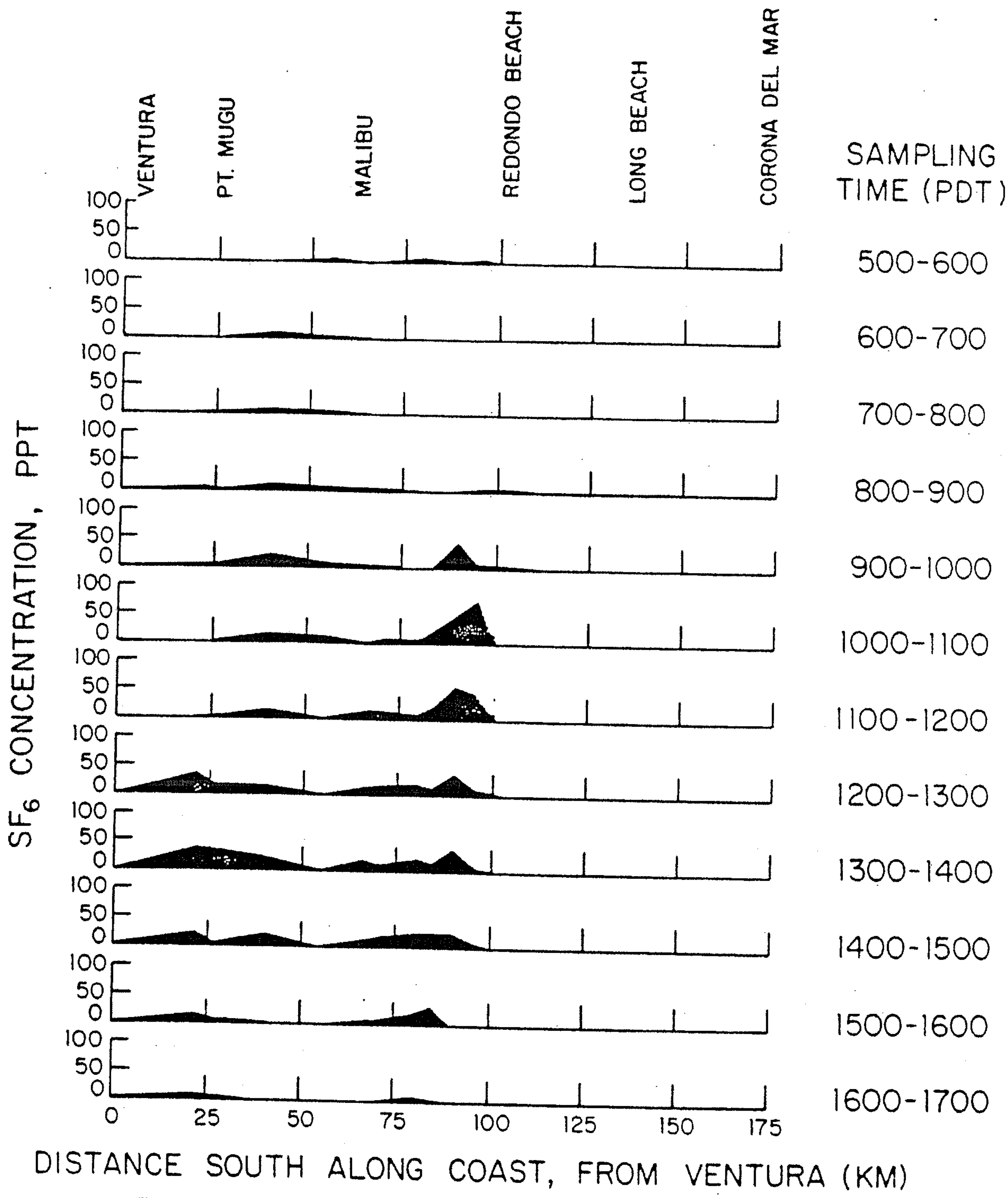

SANTA CLARA VALLEY
VENTURA
OXNARD PLAIN
SAN FERNANDO VALLEY
SAN GABRIEL VALLEY
SAN BERNARDINO VALLEY
LOS ANGELES BASIN
SANTA BARBARA CHANNEL
PT MUGU
PT DUME
MALIBU BEACH
PACIFIC PALASADES
SANTA MONICA BAY
EL SEGUNDO
HERMOSA BEACH
REDONDO BEACH
LONG BEACH
NEWPORT BEACH
CORONA DEL MAR
SAN PEDRO CHANNEL
SANTA CATALINA ISLAND
ANACAPA ISLAND
PACIFIC OCEAN
KEY
8 - SF_6 MONITORING SITE
405 - INTERSTATE 405
1 - CALIFORNIA HIGHWAY 1
SCALE 1:250,000
MILES
KILOMETERS

FIGURE 1



LOS ANGELES BASIN
SANTA MONICA BAY
PT. DUME
EL SEGUNDO
LONG BEACH
INTERSTATE 405
HIGHWAY 1
ACANIA SHIP TRACK
7/22 PDT
KEY
PLUME CENTERLINE
AT 4 A.M. FROM SURFACE WINDS
AT 4 A.M. FROM 100 M WINDS
AT 3 A.M. FROM 300 M WINDS
SCALE 1:250,000
Miles
Kilometers
JULY 22, 1977
[SF6], PPT
TIME, P.D.T.

FIGURE 2



TEST NO. 1 CONDUCTED ON 7-22-77

FIGURE 3

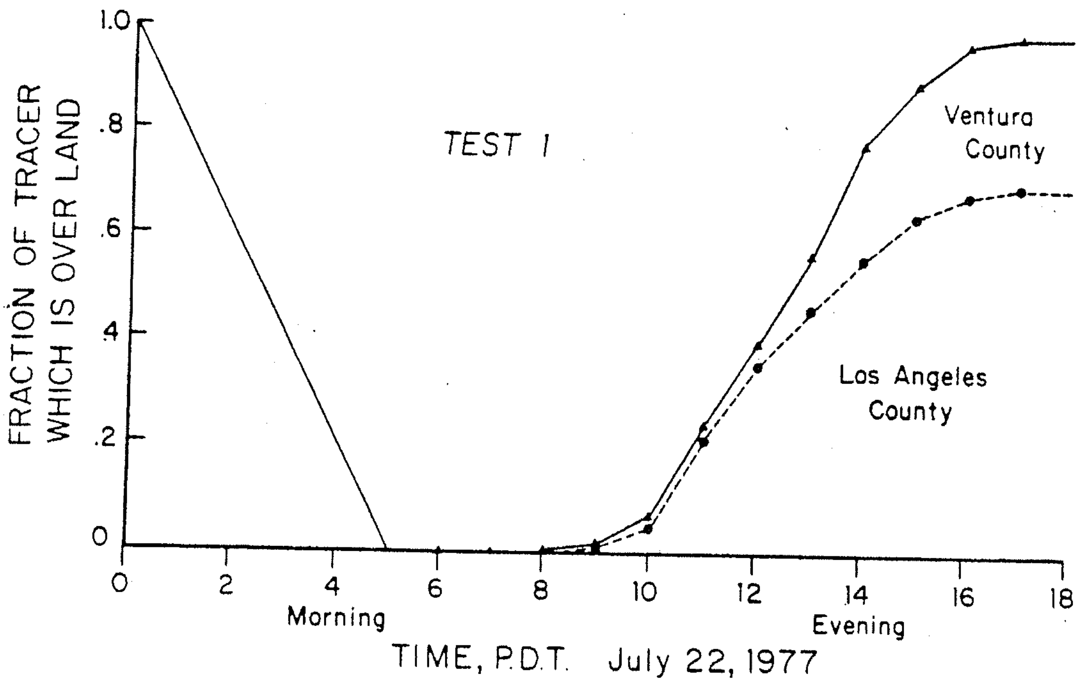


FIGURE 4a

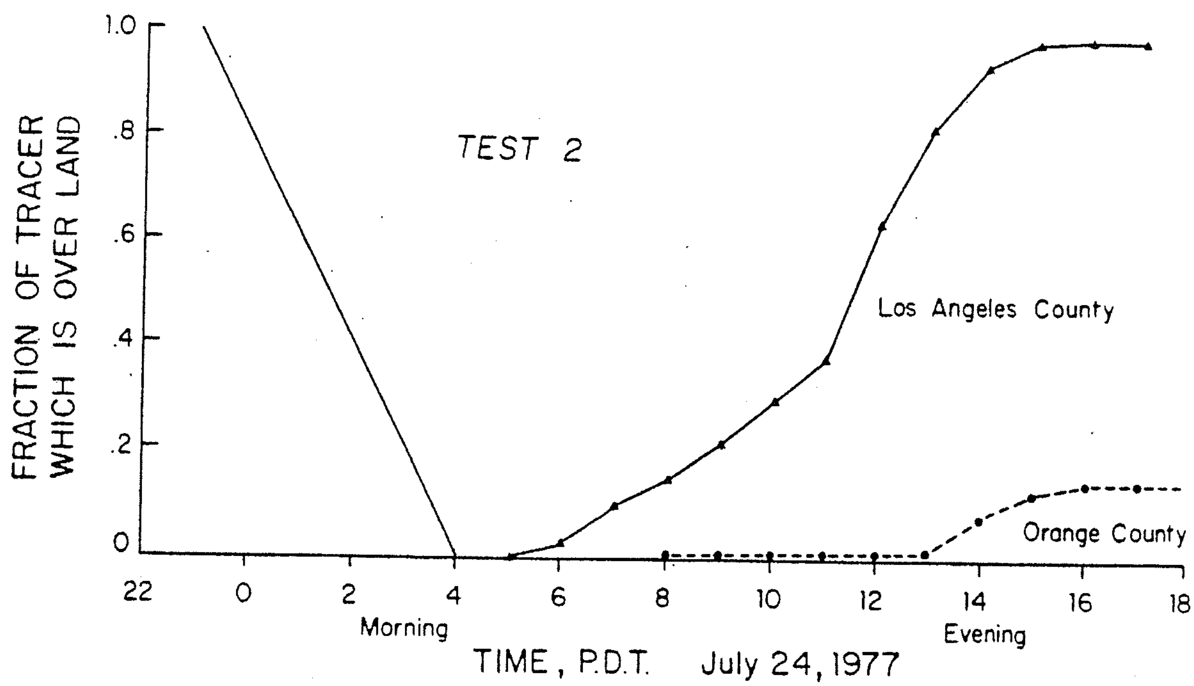
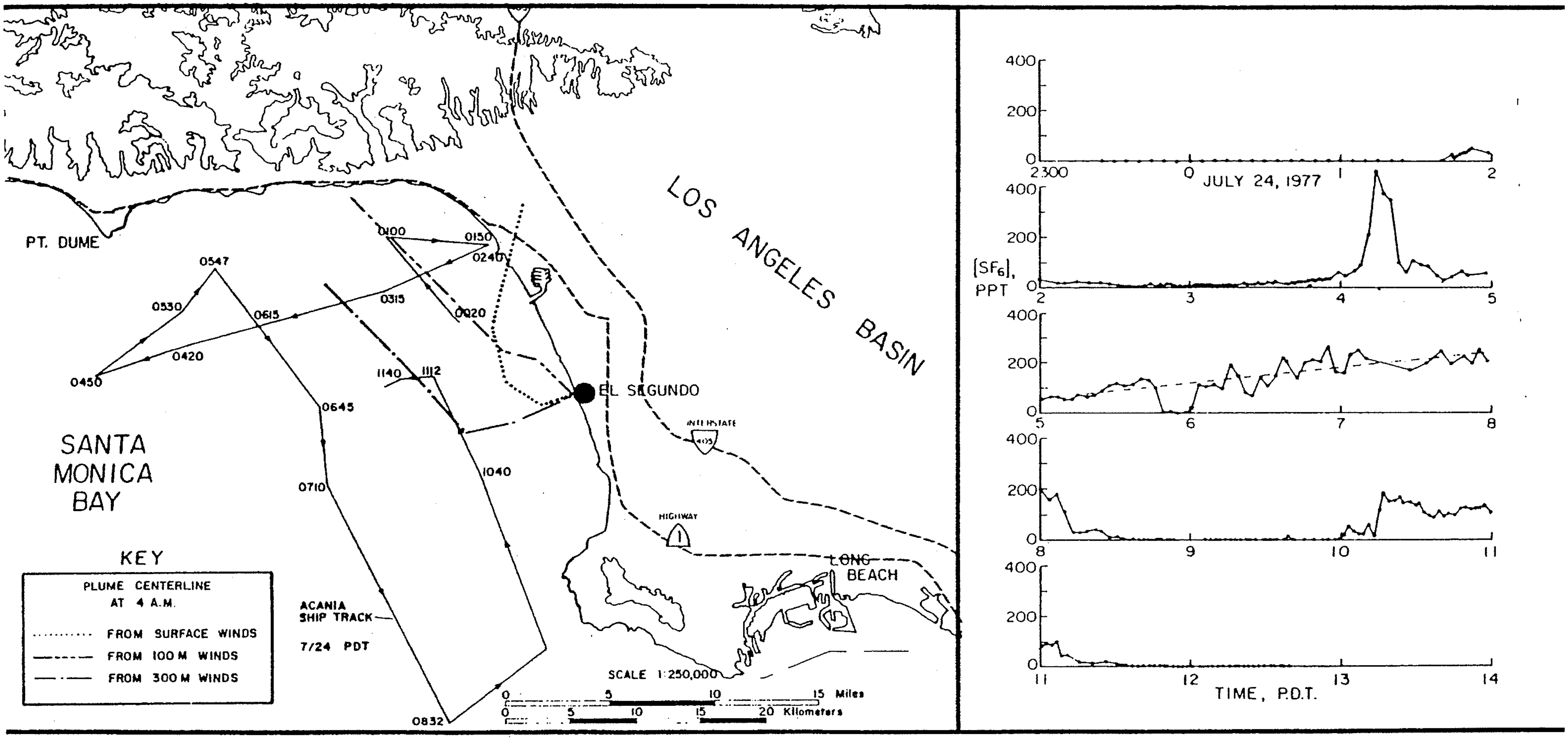
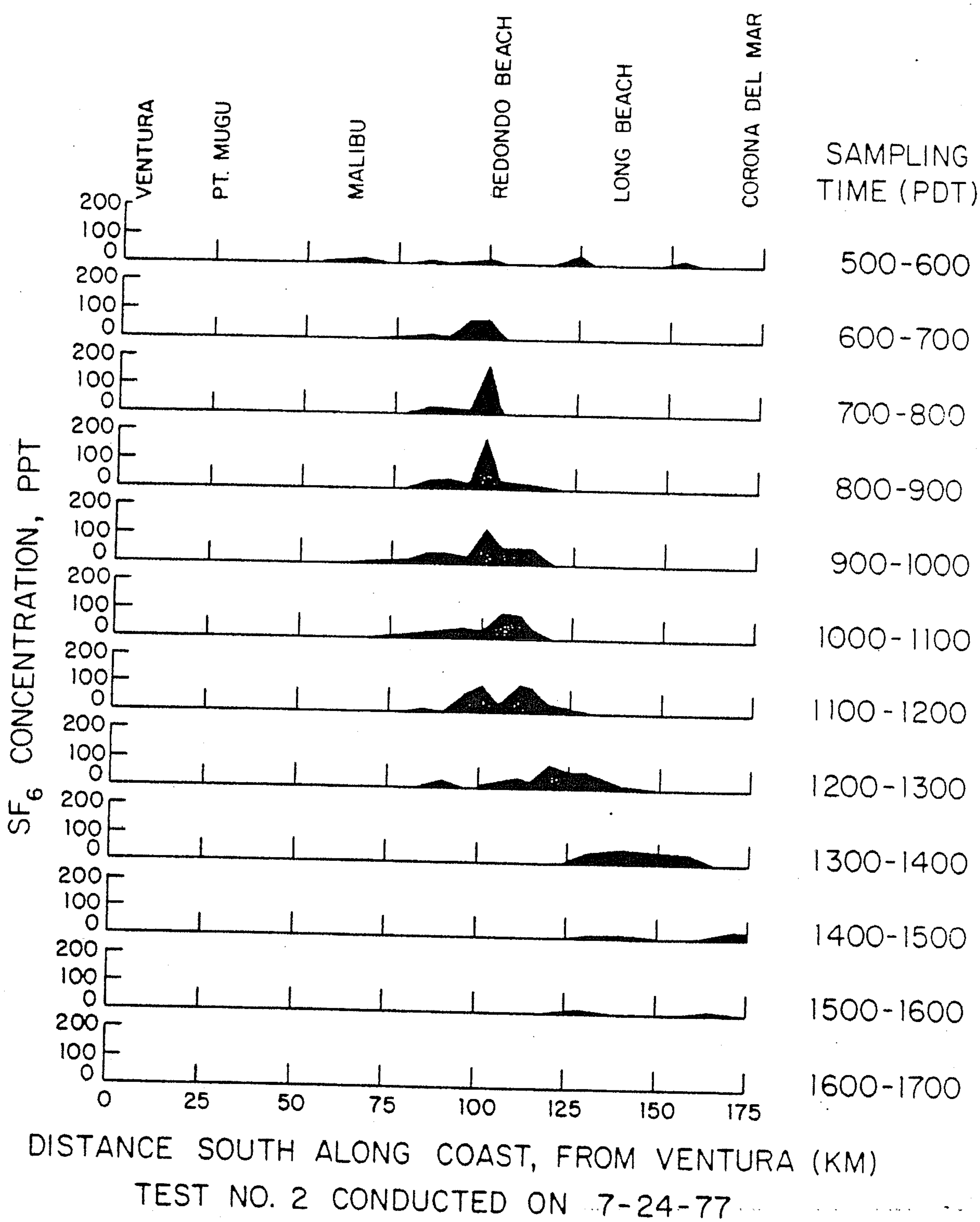


FIGURE 4b



PT. DUME
SANTA MONICA BAY
LOS ANGELES BASIN
EL SEGUNDO
LONG BEACH
INTERSTATE 405
HIGHWAY 1
0100
0150
0240
0020
0315
0547
0530
0615
0420
0450
1140
1112
0645
1040
0710
0832
ACANIA SHIP TRACK
7/24 PDT
KEY
PLUME CENTERLINE AT 4 A.M.
FROM SURFACE WINDS
FROM 100 M WINDS
FROM 300 M WINDS
SCALE 1:250,000
0 5 10 15 Miles
0 5 10 15 20 Kilometers
JULY 24, 1977
[SF6], PPT
400
200
0
2300
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
TIME, P.D.T.

FIGURE 5



VENTURA
PT. MUGU
MALIBU
REDONDO BEACH
LONG BEACH
CORONA DEL MAR
SAMPLING TIME (PDT)
200
100
0
500-600
600-700
700-800
800-900
900-1000
1000-1100
1100-1200
1200-1300
1300-1400
1400-1500
1500-1600
1600-1700
SF_6 CONCENTRATION, PPT
0
25
50
75
100
125
150
175
DISTANCE SOUTH ALONG COAST, FROM VENTURA (KM)
TEST NO. 2 CONDUCTED ON 7-24-77

FIGURE 6

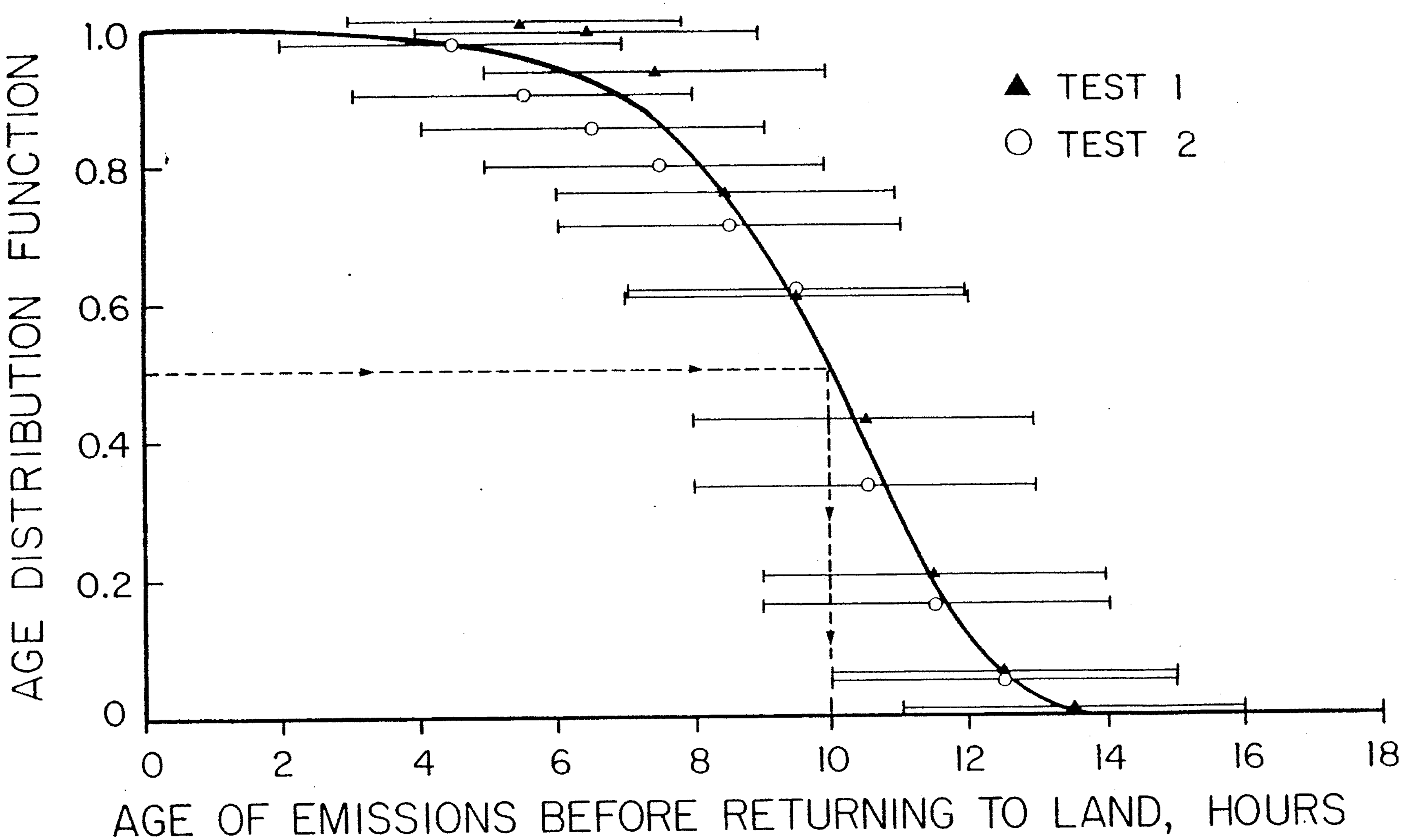

TEST 1
TEST 2
AGE DISTRIBUTION FUNCTION
1.0
0.8
0.6
0.4
0.2
0
2
4
6
8
10
12
14
16
18
AGE OF EMISSIONS BEFORE RETURNING TO LAND, HOURS

FIGURE 7

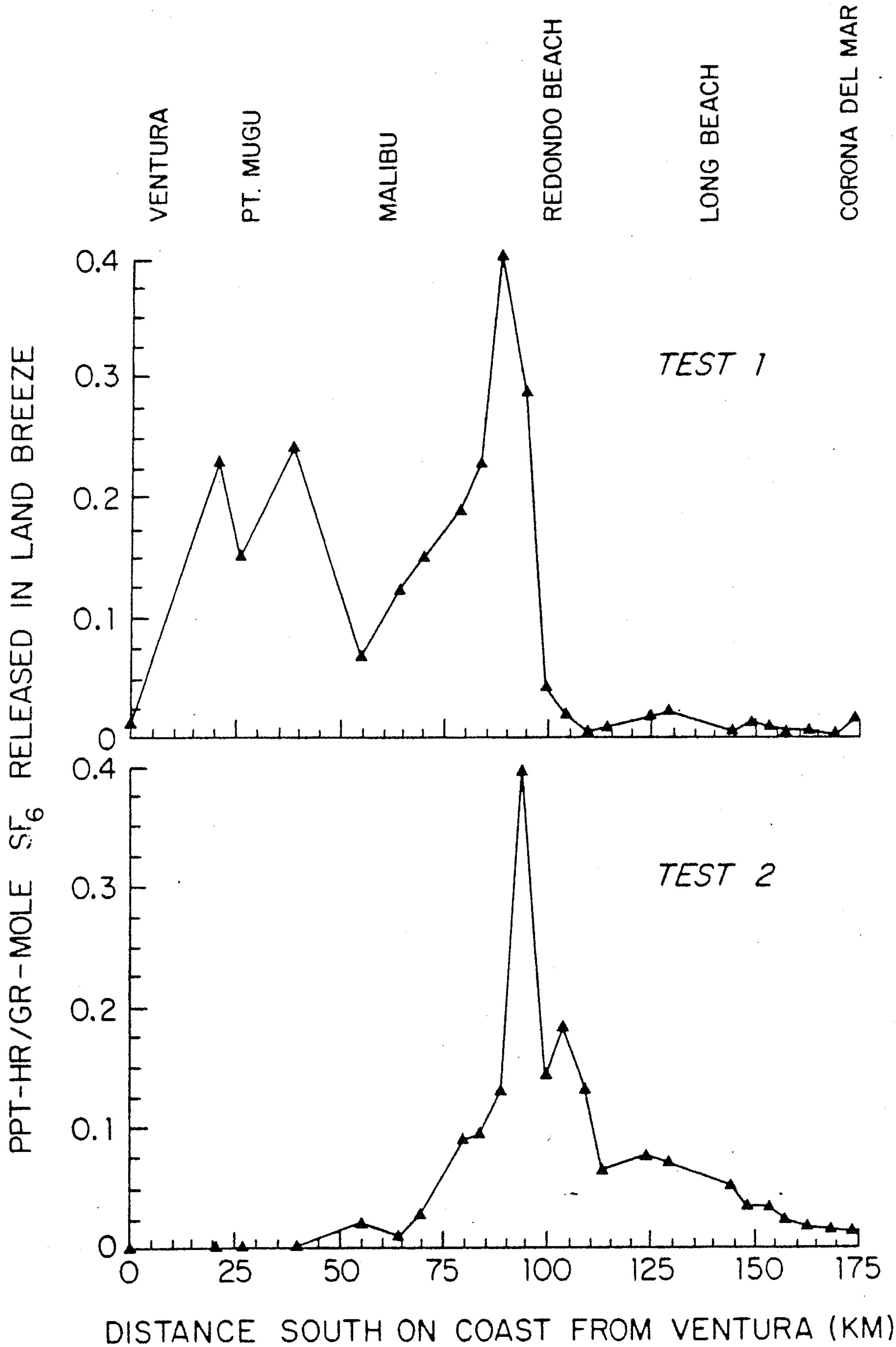

VENTURA
PT. MUGU
MALIBU
REDONDO BEACH
LONG BEACH
CORONA DEL MAR
TEST 1
TEST 2
PPT-HR/GR-MOLE SF6 RELEASED IN LAND BREEZE
0
0.1
0.2
0.3
0.4
0
25
50
75
100
125
150
175
DISTANCE SOUTH ON COAST FROM VENTURA (KM)

FIGURE 8

APPLICATION OF ATMOSPHERIC TRACER TECHNIQUES TO DETERMINE THE TRANSPORT AND DISPERSION ASSOCIATED WITH THE LAND-BREEZE MOVEMENT OF AIR OVER THE LOS ANGELES COASTAL ZONE

VOLUME 1 - EXECUTIVE SUMMARY

BY

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DECEMBER 2, 1982

ABSTRACT

This report presents the results of seven atmospheric tracer tests in which sulfur hexaflouride was used to determine the transport and dispersion of pollutants associated with the Land and Sea Breezes of the Southern California Coastal region. Two elevated releases were made from the stack of a coastal power plant into off-shore flow. A dual tracer release was made from a ship moving north along the shipping lane between Long Beach and Ventura. Four additional releases were made from the surface during both Land and Sea Breezes. A significant portion of the tracer material released returned ashore during each test. Tracer released under off-shore flow conditions returned over a large section of the coast line whereas tracer released into a sea breeze maintained a narrower plume with higher concentrations found at greater downwind distances. The variation in plume characteristics from hour to hour and test to test reflected the complexities of the wind patterns of this region. Converging and diverging wind patterns along with flow reversals contributed to the large variations observed.

The statements and conclusions in this report are those of the Contractors and not necessarily those of the State Air Resources Board. The mention of commercial products, their source of their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

INTRODUCTION

Seven large scale atmospheric tracer studies were conducted during 1977 and 1978 to probe the transport and dispersion associated with the land-breeze and sea-breeze circulation systems along the Southern California Coast. The primary tracer gas, sulfur hexaflouride (SF_6) was released during both on-shore and off-shore flow conditions. Four releases were made from land and three releases were made offshore from a boat. During one shipboard release a second tracer, bromotriflourmethane ($CBrF_3$), was also released to provide more detailed resolution in the samples collected. Twenty-nine samplers were deployed along a section of the Coast extending from Corona Del Mar in Orange County to Ventura. In addition to these hourly-average samples, a large number of grab samples were collected by teams in automobiles, boats and airplanes. All tracer samples collected were analyzed and the results are presented in Volume 3 of this report.

A brief summary of each test will be presented in this volume. A summary of tracer releases and the maximum normalized concentration measured during each test is presented in Table 1. An extended summary of select tests and analyses of special topics are presented in Volume 2.

Tests 1 and 2 involved releasing SF_6 for a 5-hour period during each of two nights from stack #4 of the power plant operated by the Southern California Edison Company. Even though a portion of the plume was apparently injected above the base of the nighttime inversion, essentially all of the tracer was observed to return across a control surface (from sea level to the base of the inversion) along the coast throughout the sea breeze regime during the following day.

The residence time distribution functions of tracer material over the sea were almost identical in both experiments. The average residence time for tracer material over the ocean was 10 hours in both cases; however, some of the tracer spent as much as 16 hours out over the sea. The horizontal dispersion of tracer was also greater than had been expected, with between 75 and 100 km of coastline impacted by the return of SF_6 from a single elevated point source. Data from both shipborne and coastal monitoring stations indicate that the path followed by the tracer over the ocean could not have been tracked accurately using trajectories constructed from conventionally available meteorological data. The results of tests 1 and 2, including a discussion of the physics of the mixing processes, are contained in Volume 2.

Test 3

The objective of test 3 was to determine the role of emission released from ship traffic operating in the prescribed shipping lane. A dual tracer release was made from the Naval Postgraduate School Research Vessel "Acania" for this study. Sulfur hexaflouride (SF_6) was released from 0530-1730 PDT as the ship moved along the shipping lane from Long Beach to a point in the Santa Barbara Channel about 25 km north of Santa Rosa Island (see fig. 1). A second tracer, Bromotriflouromethane, was also released at 50 lbs/hr along two segments of the route (0530-0830 PDT, 1230-1730 PDT) in an attempt to provide more detailed resolution concerning the segment of the route that a given SF_6 sample came from. SF_6 was detected during the course of the test at all twenty-nine sampling sites shown on figure 1. The highest concentrations were recorded at the southern sites during the on-set of the sea breeze.

Test 4

Sulfur hexafluoride was released from the Acania in the middle of the Santa Barbara Channel between 0502-0714 PDT from a location about 25 KM North of Santa Rosa Island. Grab samples collected in Santa Barbara and Ventura Counties indicated that the tracer concentrations were highest in Santa Barbara County, with some lower concentrations recorded in the Ventura area. This pattern suggests that the heaviest impact was beyond the hourly-average sampler network. The maximum normalized concentration reported was 9616 PPT/lb-mole hr^{-1} and came from a grab sample collected near Santa Barbara.

Test 5

A shore line release of SF_6 was made from the surface at El Segundo between 0200-0430 PDT on September 8, 1977. Off-shore flow prevailed during the release and the plume initially moved seaward and returned back onshore after the onset of the sea breeze. The converging wind pattern at the interface between the land-breeze and sea-breeze regimes together with flow reversals

Figure 1

ROUTE OF ACANIA ON 7/26/77

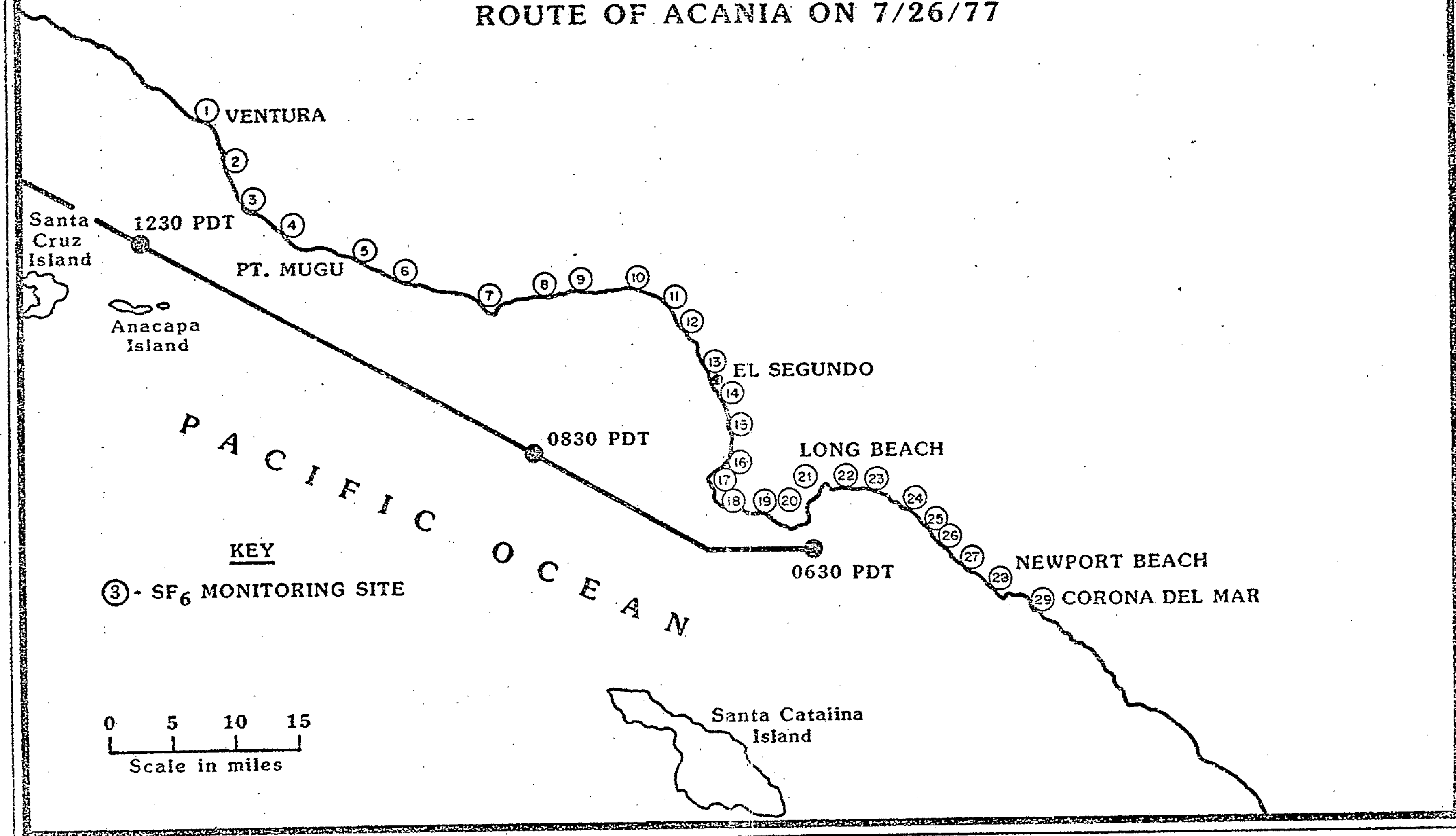

TABLE 1

SF_6 TRACER DATA

TEST NO.	DATE	RELEASE LOCATION	RELEASE TIME (PDT)	** MAXIMUM SF_6 CONCENTRATION	LOCATION OF MEASURED MAXIMUM CONCENTRATION
1	7/22/77	SCEPP* (elevated)	0005-0500	277	Playa Del Rey
2	7/23-24/77	SCEPP* (elevated)	2303-0400	244	Manhattan Beach
3	7/26/77	Shipping Lane (Fig.2)	0530-1730	2577	Sunset Beach
4	7/28/77	Middle of Santa Barbara Channel	0502-1714	9615	Santa Barbara
5	9/8/77	SCEPP* (surface)	0200-0430	566	Malibu
6	9/13/77	Twenty-Two Miles West of SCEPP*	0900-1400	796	Manhattan Beach
7	7/13/78	SCEPP* (Surface)	0900-1500	6562 (Grab Sample)	Eight Miles Down Wind of Release Site

*SCEPP - Southern California Edison Power Plant at El Segundo (Unit 4)

** Concentration Normalized to PPT/LB-MOLE SF^6 HR^{-1}

during the transition period appear to have mixed the plume and spread it over a large area. The tracer was detected at samplers located over a twenty mile wide zone and concentrations were relatively dilute. The major part of the plume returned on-shore north of the release site and a maximum normalized hourly average concentration of 339 PPT/lb-mole hr $^{-1}$ was recorded in the Malibu area.

Test 6

An off-shore release of SF_6 was made between 0900-1400 PDT on September 13, 1977. The release was made from a boat about twenty-two miles due west of El Segundo at the on-set of the sea breeze. The plume moved directly onshore near El Segundo and covered a ten mile wide section of the Coast line. The highest normalized hourly average tracer concentration measured during this test was 796 PPT/lb-mole hr $^{-1}$ collected at Manhattan Beach.

Test 7

SF_6 was released from the surface at El Segundo during the period 0900-1500 PDT. The tracer moved eastward across the Los Angeles basin and passed thru Banning Pass at 2000 PDT and concentrations in the pass remained above 10 PPT until 0445 PDT the following day. A traverse on the afternoon after the tracer release along highway 534 near the Colorado River measured SF_6 concentration along a segment over 85 miles long with numerous SF_6 concentrations over 10 PPT.